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Dibaryons as carriers of strong internucleon interactions and a basis for nuclear physics based on QCD

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New concept of intermediate- and short-range nuclear force proposed by the authors a few years ago is discussed briefly. The general concept is based on an assumption on generation of the dressed dibaryon in intermediate state in NN interaction. This new mechanism has been shown to lead not only to numerous new predictions in hadronic physics but also should be responsible for a large portion of nuclear binding energy and properties of nuclear wavefunctions at high momenta.

Keywords: Dibaryon; NN interaction; σ-meson.

1. Why the dibaryon?

In the talk we will try to convince the readers that dibaryons should be considered as basic degrees of freedom in nuclear (similarly to nucleons and pions) and also in hadronic physics. Moreover, they may serve as a most appropriate basis for non-conventional nuclear physics based on QCD. These claims are based on some strong arguments and also fundamental theory. Due to a limitation of space, we present here a few such arguments only (for more detailed arguments see e.g. refs. [1,2]):

(i) A few recent studies made independently [3] have demonstrated with evidence that traditional OBE-based approach to the basic intermediate-range attraction in NN system, which uses the scalar σ-meson exchange (or the t-channel two-pion exchange with intermediate $\pi\pi$ interaction in scalar-isoscalar channel) fails to reproduce the strong intermediate-range NN attraction which is basis for nuclear binding in all traditional force models.

(ii) The values of cut-off parameters Λ_{mNN} and $\Lambda_{mN\Delta}$ ($m = \pi,\ \rho,\dots$) taken in all OBE-based NN models ($\Lambda_{mNN} \sim 1.5 \div 1.7$ GeV/c) are at least in 2 –3 times higher than the values needed to describe quantitatively the $\pi^{\pm}$-production in pp-collisions or π-meson absorption in d, ³He etc. and also as compared with all theoretical predictions [1,2]. So, there is no one consistent choice for the cut-off parameters Λ_x able to describe correctly both elastic and inelastic NN scattering or π-meson production and absorption.

(iii) Many hadronic experiments with nuclei done in the kinematical region forbidden for a single-nucleon interaction (the so-called cumulative experiments) show a large yield of particle products, which can be explained only by an interaction of incident hadron with tightly correlated few-nucleon clusters in nuclei, the degree

of short-range correlations being incompatible with any traditional nuclear force models, but may be interpreted quite naturally as a manifestation of multi-quark (i.e. $6q$-, $9q$-,...) bags in nuclei. Moreover, it was claimed by Jaffe many years ago that QCD does not forbid the existence of such multi-quark bags and if *they do not exist there should be the special QCD-based forbidness which we do not know now.* So, the incorporation of dibaryons in hadronic and nuclear physics might help to overcome such fundamental difficulties and to put a proper cornerstone to the ground of QCD-based nuclear physics.

2. Microscopic and EFT approach to intermediate- and short-range NN interaction based on intermediate dibaryon generation

If the mass of mesons exchanged between two nucleons exceeds 500 MeV (this relates to all mesons except pion) the respective characteristic scale for meson-exchange NN interaction is less than 0.5 fm, i.e. the meson exchange proceeds when two nucleons overlap deeply and thus the picture of two isolated nucleons which are exchanged with a such heavy meson gets fully meaningless. The picture becomes much closer to a unified $6q$-bag surrounded with π-, σ, ρ-, etc. mesonic fields. We developed the respective microscopic quark-meson model for such dressed six-quark bag as an intermediate in a short-range NN interaction (see Fig. 1) [1,2]:
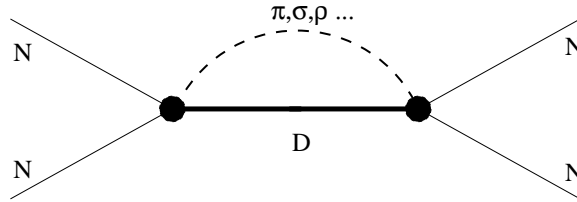

Fig. 1. *s*-channel mechanism for NN interaction with an intermediate dibaryon dressed with π-, σ, ρ-, etc. mesonic fields.

This *s*-channel mechanism replaces the conventional *t*-channel (i.e. Yukawa-like) mesonic exchange at ranges $r_{NN} \lesssim 1\,\text{fm}$. Using this mechanism as a guide we constructed [2] the respective potential model for NN interaction which easily fits (with a few free parameters only) the NN phase shifts at lower partial waves until 1 GeV and higher. This simple model predicts the deuteron properties even more accurately than the best modern phenomenological NN potentials like Argonne, Nijmegen etc. models.

Recently, this new force model has been reformulated [1] using a fully covariant effective field theory (EFT) approach. In the approach the intermediate dibaryon is described on the basis of $NN \to D(CC) \to NN$ transition (CC means here two color three-quark clusters connected by a gluonic string which form the dibaryon D). The amplitude of this transition can be represented through the non-local Lagrangian density:

$$M_{fi} = i\langle 4,3|\text{T}\left[e^{i\int dx dx' \mathcal{L}_{\text{int}}(x,x')}\right]|2,1\rangle - i\langle 4,3|\text{I}|2,1\rangle,$$

where T means time-ordering while the bra and ket $|2,1\rangle$ and $\langle 4,3|$ relates to the initial and final nucleons with 4-momenta p_2, p_1 and p_4, p_3 respectively. The nonlocal

Lagrangian density $\mathcal{L}_{\text{int}}(x_1, x_2) = \mathcal{L}_{DN} + \mathcal{L}_{Dm}$, includes two terms: $\mathcal{L}_{DN}$ describes the transition to a bare dibaryon state with possible spins $S = 0, 1$ while $\mathcal{L}_{Dm}$ represents the dressing of the bare $6q$-bag with its meson cloud [1]. The amplitude M_{fi} can be expressed through the dibaryon wavefunctions and respective dibaryon propagators $\mathcal{G}^s(x_1, x_2; x_3, x_4)$ for which we solve the Dyson equation using the basis of relativistic (Dirac) oscillator. After lengthy algebra one gets eventually the analytical expression for relativistic NN potential which includes also an imaginary part responsible for the meson production in NN collisions. The potential includes the matrix elements of polarization operator, the latter can be represented through the graphs:
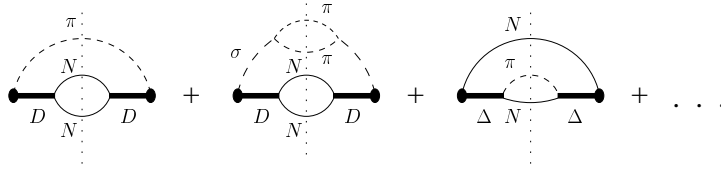

Fig. 2.   Several of the possible loops taken into account in calculation of polarization operator of dibaryon. They correspond to the dressed bag state.

If the total energy exceeds that of the 2π-threshold the 2π-production process in scalar-isoscalar channel will proceed via intermediate (renormalized) σ-meson with enhanced probability [1,2] which can naturally explain a few puzzles related to 2π-production cross sections in pp, pn, pd etc. collisions (e.g. the ABC puzzle etc.).

3. Dibaryons in nuclei and hadronic processes

Appearance of dibaryon mode in the fundamental NN interaction must result in the appearance of the dibaryon components in nuclear wavefunctions. In fact, it was shown in our extensive $3N$ calculations [4] with the dibaryon model for nuclear force that the presence of the strong scalar-isoscalar field in the dibaryon leads to the strong exchange force between dibaryon and nucleons surrounding it (this force is nothing else but a specific three-body force (see Fig. 3). It is important to stress here that the σ-meson mass and width in these graphs are renormalized noticeably due to partial chiral symmetry restoration around the dense multiquark bag. So, the σ-meson mass gets much lower and has been estimated to be the value $m_\sigma \sim 350 \div 380$ MeV which should be compared to the free σ-meson mass ~ 550 MeV. So that, the renormalized σ-meson around the bag resembles the quasi-stable scalar σ-meson of the old OBE models. The exchange by the quasi-stable σ-meson leads inevitably to strong attractive force between dibaryon and other nucleons.In our $3N$ calculations [4] we have found that this new three-body force gives, at least, a half of the total nuclear binding energy and contributes strongly to other important observables. Moreover, the total weight of the dibaryon component in $3N$ wavefunction is as large as 10% or even higher. This large admixture of
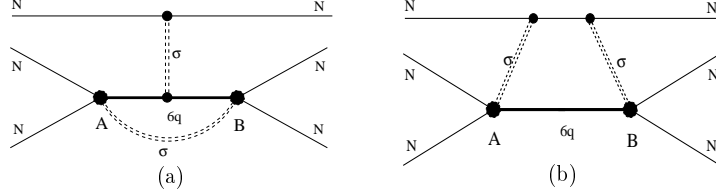
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Fig. 3.   The graphs illustrating the new $3N$ scalar force induced by σ-exchange between the dressed bag and third nucleon.

the very compact multi-quark bag components in all nuclei should play decisive role in short-range NN correlations and description of nuclear properties at high momentum and energy transfers.

Furthermore, according to the general principles of quantum theory a new degree of freedom must lead to respective new currents, e.g. in e.-m. processes. So that we derived such a new isoscalar current in deuteron, which gives very essential M1- and E2-contributions to circular polarization of γ-quanta in $\vec{n}p \to d\vec{\gamma}$ radiation capture process with thermal neutrons [5], and also to deuteron magnetic form factor at $Q^2 \sim 1$ GeV and some corrections to deuteron magnetic moment. The intermediate dibaryon should contribute strongly also to numerous hadronic processes like single- and multi-meson production and near-threshold production of heavy mesons (ρ, ω ...) in pp, pd etc. collisions at intermediate energies 1 - 5 GeV [1,2], in numerous electro- and photoproduction processes like $d(\gamma, 2\pi^0)$ and two-nucleon electro- and photo-disintegration processes like $^3\mathrm{He}(e, e'pp)$, $A(\gamma, pp)$ etc.

Thus, the characteristic features in the majority of hadron-nucleus or photon-nucleus processes accompanying with high momentum or energy transfer must be related to the interaction of high-energy projectile with dibaryon as whole. The latter process should be described in terms of QCD-based approaches. Hence, one can summarize: *the dibaryon physics can be viewed as a very appropriate "window" through which the full QCD enter the whole nuclear physics.*

References

1. V.I. Kukulin and M.A. Shikhalev, *Phys. At. Nucl.* **67**, 1536 (2004); *Ann. Phys.* (2005).
2. V.I. Kukulin, I.T. Obukhovsky, V.N. Pomerantsev, and A. Faessler, *Int. J. Mod. Phys. E* **11**, 1 (2002).
3. E. Oset, H. Toki, M. Mizobe, and T.T. Takahashi, *Progr. Theor. Phys.* **103**, 351 (2000); M.M. Kaskulov and H. Clement, *Phys. Rev. C* **70**, 014002 (2004).
4. V.I. Kukulin, V.N. Pomerantsev, M.M. Kaskulov, and A. Faessler, *J. Phys. G* **30**, 287 (2004); V.I. Kukulin, V.N. Pomerantsev, and A. Faessler, *J. Phys. G* **30**, 309 (2004).
5. I.T. Obukhovsky et al., to be published elsewhere; V.I. Kukulin and M.A. Shikhalev, Proceeds. XXIII Int. Workshop on Nuclear Theory, Ed. V. Nikolaev, Rila, Bulgaria, June 2005.